ORIGINAL ARTICLE

A Morphology Approach for Fault Location on Transmission Lines

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Abstract: This paper presents a heuristic method for fault location in transmission lines. It is established based on synchronized voltages sampling in line terminals using morphology approach. The proposed method uses only pre and during fault voltage phasors while traditional distance protection approaches require current transformers (CT) (with the issue of CT saturation and their errors), knowledge of line parameters and Thevenin impedance calculation. The proposed method is based on the voltage variations in the stationary reference frame (α-β). The changes of enclosed area of the voltage curve in the Clark coordinate due to fault is selected as the location criteria. Results indicates that the method is able to estimate fault point distances. However, the estimated fault point tolerates in a variable zone.

Keywords: Fault Location; Morphology; Synchronized Voltage Measurement; Current Transformer Elimination

Introduction

Transmission lines are subject to faults at any voltage level. To expedite repairs and restoration of power, it is important to know where the fault is located. Due to this fact, a lot of methods have suggested to increase the accuracy and decrease the distance protection cost. The majority of offered methods use the measured voltages and currents of faulted system to develop the algorithm and fault location. Independence of fault location algorithm from some measurement device (such as CTs) can increase the process accuracy. Actually, the over voltage and transient state of power network during the fault period causes inappropriate operation of CT (CT saturation in extra fault currents is inevitable). It causes inappropriate performance of feeding relays that leads to incorrect fault location. In other words, the main drawback of CT through the fault is the risk of magnetic core saturation. To solve this problem, many methods have been suggested such as selection of the CT with more accurate measurement class and more relevant core. In spite of acceptable and high accuracy of these methods which use both system parameters (voltages and currents), developing the new methods independent of current measurement is needed due to CT inherent saturation issues.

Several current independent techniques offered to identify the fault location on transmission lines [1-5]. Among them, [1,2] presented a technique based on voltage measurement in multi-terminal network. Also, [3,4] decrease the voltage measurements to one (local) terminal in a two–terminal network. In spite of aforementioned advantages, proposed technique in [3] wasn't independent of fault type and fault resistance and need to recognize the fault type before calculations. Generally, the two-terminal location methods are more accurate than one terminal method and are able to minimize or eliminate the effects of fault resistance, loading, and charging current. Many fault location techniques are developed due to the recent advancement in the field of gathering data, synchronized measurements based on Global Positioning System (GPS) and intelligent signal processing systems.

Besides the mentioned voltage based methods, new methods are presented that use fundamental frequency components of voltage. These methods are called as Synchronized Voltage Measurement [5-10]. The proposed methods by Brahma in [5,6], pass over the current dependency in the calculation of fault location, the techniques are not independent of fault type and fault resistance. In order to obviate this problem, Firouzjah et al. [7-10] proposed a synchronized voltage based method independent of fault types, fault resistances, fault inception angles and power loading angles.

The methods listed in [5-10] eliminated CT requirement in fault location process. However, their main disadvantage is Thevenin impedance calculation of two sides of the transmission line.

Therefore, establishing a current independent method independent of system parameters will be expedient. In contrast with classical techniques such as Fourier Transform, development of simple and fast signal processing methods that are will be expedient. Morphological-based methods are suitable alternatives in this application to achieve protection scheme independent of system parameters. The morphology is concerned with the shape of a signal waveform in the time domain rather than the frequency domain. The morphology has been widely used in the areas of image processing, but only a few investigations have been attempted for signal processing. The main advantage of this technique is the capability of matching with non-periodic transient signals and not restricted to periodic signals. It is able to accurately and reliably extract the signal components without causing any distortion, as it is a time-domain signal processing method without performing any signal integral transforms [11]. Mathematical morphology (MM) is introduced as an applicable tool to non-periodic transient signals [12].

The morphological technique has been applied to fault location based on fault transient extraction [13-15]. [13, 14] use the multi-resolution morphology gradient operator to extract transient features from fault-generated voltage and/or current signals propagating along transmission lines during a post-fault period. A wavelet-based method participates with morphology in [15]. The application of these techniques effectively leads to a reduction of fault restoration times and the system operation cost during maintenance. [16] proposed a MM-based fault location method to detect the arrival time and polarity of the voltage traveling waves. In noisy cases [17, 18], the traveling wave method combined MM and wavelet analysis to filter the noise. [16, 19-20] combined traveling wave and MM in fault location and classification. The results show that the process is low affected by the fault type, resistance and location.

Recently, [21-22] proposed reliable a fast fault detection and classification method using MM technique. The proposed algorithm is validated under high-impedance faults. The main contribution of new MM based fault location techniques is fast process speed.

According to the mentioned advantages of the morphological method, a fault location algorithm with the help of Morphology technique is proposed that is independent of the system parameters and current measurement. MATLAB simulation results are presented to show the accuracy of a technique for two–Terminal networks in different fault types and resistances.

Morphology Based Fault Location Method

Concept

The basic principle of protective relaying of power systems has not changed for more than half a century. Almost all power system protective relaying algorithms are dominated by integral transforms such as the Fourier transform and the wavelet transform. The integral transform can only provide an average attribute of the signals or their components. The accuracy of the attribute extraction is significantly sacrificed by the assumption of the periodicity of the signals if the integral transform is applied to transient signals. It is also well known that the signals are liable to be contaminated by noise in the form of exponentially decaying DC offsets, high-frequency transients, harmonic distortion, errors caused by non-linearity in the response of the sensors, and unwanted behavior of power systems. This contamination is often provoked by fault conditions, just at the time when the protection relay is required to respond and trip the circuit breaker to limit the damage caused by the fault.

On the other hand, in most protection relays, complex computation has to be undertaken within a sampling interval to calculate the coefficients relevant to the attributes of the signals by using the integral transform. To calculate the relaying algorithms, extra computing process and facilities are required in case of fast transients and high-order harmonics. Therefore, it can be seen that the current power system relaying algorithms suffer from many problems including accuracy, fast responses, noise, disturbance rejections, and reliability.

To tackle the problems of distorted waveforms, disturbances and transient components of fault voltages and currents, identification of the shapes of complex waveforms is ideally required instead of the analysis of periodic characteristics (which is undertaken by the currently used integral transform to obtain the knowledge of distorted signals indirectly). However, there is currently no generic methodology available for designing a protection relay that is able to detect the shapes of signals.

This paper introduces morphology for the design and operation of power system relays. Morphology has been designated as a new branch of signal processing, which is totally different from the integral transform-based methods in basic principles, algorithmic operations, and approach.

The protective relaying algorithms have been updated from electromechanical components to microprocessors. The methodologies have remained unchanged for more than half a century. Over this long period of time, integral transform-based methods have played a major role in relay design. These methods work principally based on assumption that the fault voltage and current are periodic signals. As mentioned above, the morphology based technique is able to deal with transient signals and non-periodic signals, which are prevalent in power system fault scenarios.

Proposed Algorithm

In this section a morphology based method using the Clarke's transformation is proposed to determine the fault location estimation on the two terminal transmission lines. This method presents a heuristic approach, which is based on the Clarke's transformation known as alpha-beta transformation, which is a transformation of a three-phase system into a two-phase system [23]. Clark transformation is one of the best de-coupling techniques for three phase parameters [24]. This paper performs a two-ended line. The transmission line model considered for this paper has been shown in Figure 1. Figure 1 shows a single line diagram of a two-terminal transmission line. S_1 and S_2 and Z_{s1} and Z_{s2} are Thevenin equivalent system models at bus 1 and bus 2 respectively. L is the length of a transmission line with π equivalent model. To evaluate fault conditions, a fault is applied to the line. Fault point is located with the distance of L_1 from bus 1 and L_2 from bus 2 in. The faulted system is shown in Figure 2.

It is clear when an unknown fault occurs on the line; the sending and receiving sides' voltages are dropped. Due to this fact, several simulations have been carried out to derive the relation between fault location and voltage drop. This paper focuses on analyses of signal shape space. Therefore, the three-phase voltages at the sending and receiving sides are transferred into α-β stationary reference frame.

$$\left[f_{\alpha\beta 0}\right] = \left[T_{\alpha\beta 0}\right]\left[f_{abc}\right] \tag{1}$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2}$$

As known, in this frame, the three-phase signals, changed into a circular area. This concept is illustrated in Figure 3. The pre-fault and during fault voltages are transferred into the α-β frame. As this figure, pre-fault α-β shape space is larger than during-fault space. It can be realized when a fault occurs near to a bus, its voltage drops more. Therefore, the faults near to the sending side cause larger α-β shape space variation than the faults near to the receiving side which are shown in Figure 4. As mentioned, the fault location criterion can be established based on α-β shape space variation.

$$D_{S1} = \frac{A^{\circ}_{S1} - A^{f}_{S1}}{A^{\circ}_{S1}} \tag{3}$$

$$D_{S2} = \frac{A^{\circ}_{S2} - A^{f}_{S2}}{A^{\circ}_{S2}} \tag{4}$$

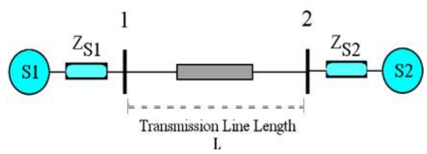

Figure 1. Single line diagram of a two-terminal transmission line.

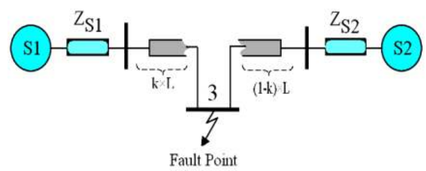

Figure 2. Transmission line during fault.

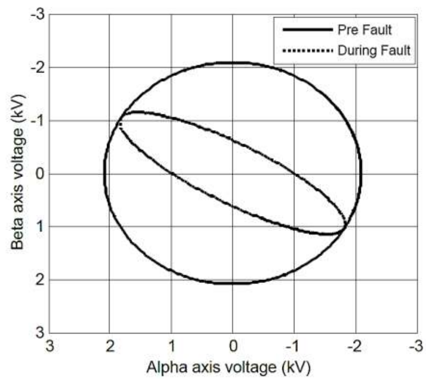

Figure 3. The pre-fault and during fault voltages in α-β frame.

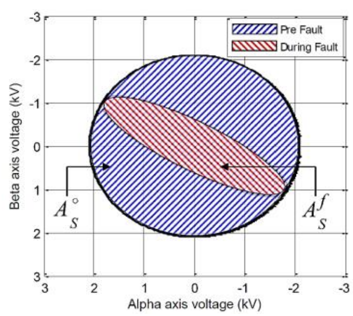

Figure 4. Pre-fault and during fault voltages α-β shape spaces.

where: A°_{S1} and A°_{S2} are the α-β shape space variation of the sending and receiving a pre-fault voltage, respectively. A^{f}_{S1} and A^{f}_{S2} are the α-β shape space variation of the sending and receiving a during-fault voltage, respectively.

The method used to estimate the amount of enclosed area in the curves of Figure 4 is as follows. First, the measured signal in each period (pre and post fault) is transferred to the α-β coordinates. These points are inside an ellipse. With a sampling frequency of 10 kHz, there are N=200 samples in a period.

$$\theta=\frac{2\pi}{N}=\frac{2\pi}{200}$$
$$R_{[n]}=\sqrt{V_{\alpha[n]}^{2}+V_{\beta[n]}^{2}} \qquad (5)$$

Accordingly, we can have 200 triangles which the area of each triangle (see Fig. 5) is approximated by the following equation:

$$S_{[n]}^{Triangle}\approx\frac{R_{[n]}^{2}?\theta}{2}$$
$$S^{Area}=\sum_{n=1}^{N=200}S_{[n]}^{Triangle}=\sum_{n=1}^{N=200}\frac{R_{[n]}^{2}?\theta}{2} \qquad (6)$$

Eventually the area of the enclosure is calculated by:

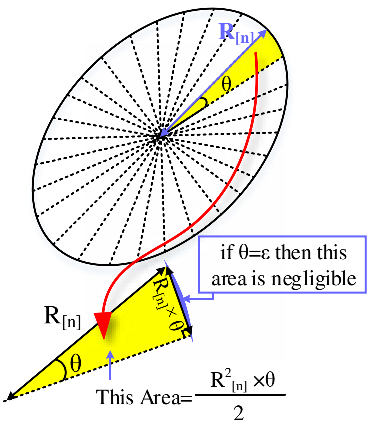

Figure 5. Calculation of the α-β shape space.

With the D_{S1} and D_{S2}, the final criterion is proposed as:

$$K_1=\frac{D_{S2}}{D_{S1}} \qquad (7)$$

$$K_2=\frac{D_{S1}}{D_{S2}} \qquad (8)$$

The K_1 and K_2 represent per unit fault distance from the Bus 1 and 2, respectively. The K_1 is lower than K_2 For the faults near to the bus 1. Also, The K_2 is lower than K_1 For the faults near to the bus 2. Therefore, according to the K_1 and K_2, the fault side can be determined. In addition, analyses of the proposed factors help to establish fault location algorithm. The flowchart of the proposed algorithm is shown in Figure 6.

Results and Discussion

Simulation for a 200 km, 400 kV two–terminal transmission line was carried out. The model is established using MATLAB/Simulink to run fault simulation for data generation. Table 1 shows the compensated line and the Thevenin impedance parameters at both ends used in simulation [8]. The performance of proposed fault detection algorithm is evaluated for five fault types (LG, LLG, LLLG, LL, LLL).

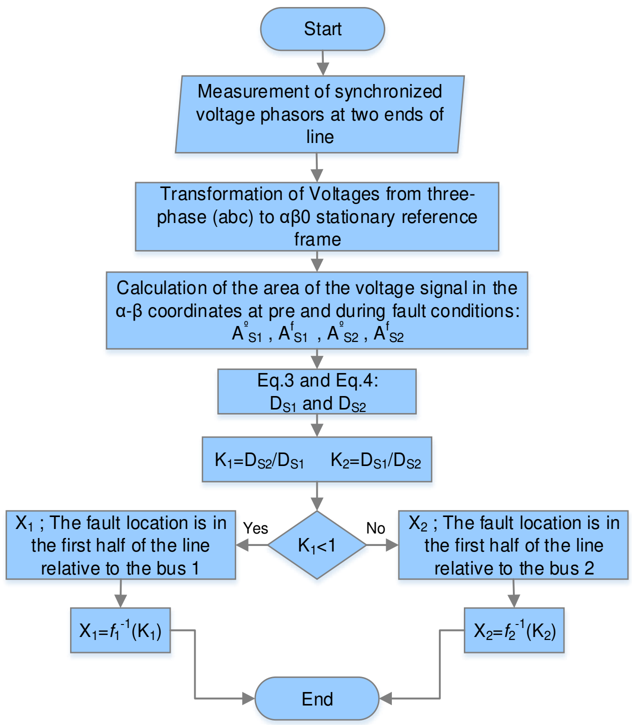

Figure 6. Proposed algorithm.

As shown in Figure 7, a number of K_1 and K_2 factors for several fault types (include of LG, LLG, LLLG, LL, and LLL) and fault resistance (10 and 100 ohms) in a 200 km transmission line is achieved by MATLAB simulations. Figure 8 shows the previous figure in the range of (0,1). According to these figures, when a fault occurs near to the sending bus (the fault point distances are between 0 and 100 km) the K_1 factor is smaller than 1 and the K_2 factor is larger than 1.

Table 1. System data used for the transmission line model.

Parameter	Symbol	Value	Unit
Transmission line Positive/Negative sequence	$R^{+,-}$	0.24916	Ω /km
	$L^{+,-}$	1.55627	mH / km
	$C^{+,-}$	19.469	nF/ km
Transmission line Zero sequence	R^0	0.60241	Ω / km
	L^0	4.8303	mH / km
	C^0	12.0667	nF/ km
Line Length	L	200	km
Voltage A		$408\angle 0$	kV
Voltage B		$387\angle -15$	kV
Thevenin Impedance	$Z_{S1}^{+,-}$	17.177+j45.528	Ω
	Z_{S1}^{0}	2.5904+j14.732	Ω
	$Z_{S2}^{+,-}$	15.31+j45.924	Ω
	Z_{S2}^{0}	0.7229+j15.128	Ω

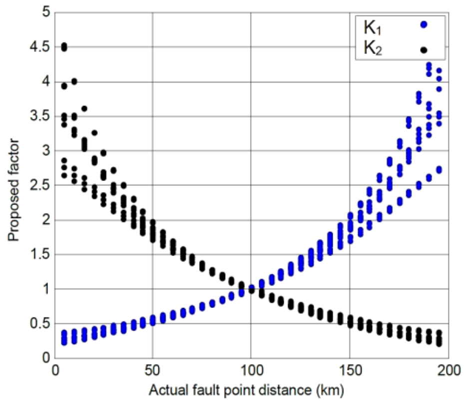

Figure 7. The K_1 and K_2 factors for several fault types and resistances in transmission line.

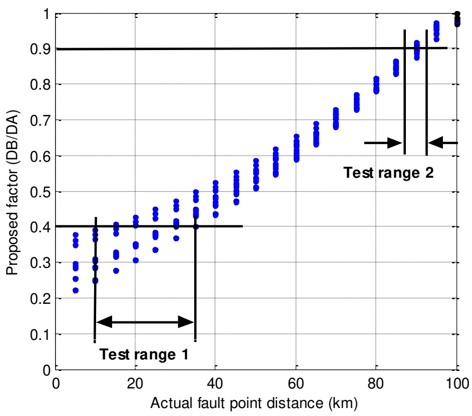

Figure 8. The K_1 factor for several fault types and resistances in right side of the line.

Also, when a fault occurs near to the receiving bus (the fault point distances are between 100 and 200 km) the K_1 factor is larger than 1 and the K_2 factor is smaller than 1. The variation of K_1 and K_2 factors in Figure 8 can be considered as a look-up table to achieve fault point distance. Assuming:

$$K_1 = f_1(x_1) \quad (9)$$

$$K_2 = f_2(x_2) \quad (10)$$

where, x_1 and x_2 are fault point distances from S_1 and S_2 buses, respectively. Therefore, the fault point distance can be achieved by:

$$\text{if} \quad K_1 < 1 \quad \rightarrow \quad x_1 = f_1^{-1}(K_1) \quad (11)$$

$$\text{if} \quad K_2 < 1 \quad \rightarrow \quad x_2 = f_2^{-1}(K_2) \quad (12)$$

If K_1 is smaller than 1 and K_2 is larger than 1, the determined fault point distance is from bus 1. If K_2 is smaller than 1 and K_1 is larger than 1, the determined fault point distance is from bus 2. For example, for K_1=0.4 (K_2=2.5), the fault is on the right side of the transmission line. As shown in Figure 9 (due to the non-functional behavior of f_1 and f_2), every value of K_1 and K_2 lead to a range of fault points. Therefore, the fault side is determined accurately and its location is estimated in variable range having the values of K_1 and K_2. According to the Figure 9, this range is maximum near S_1 bus and minimum in the middle of the transmission line. The test ranges 1 and 2 indicate this concept. As shown in this figure, range 2 is smaller than test range 1. Figure 9 shows the possible distance (in percentage of total line length) for fault location versus K_1. As an example, for K_1=0.6, possible distance is 26.5% to 32 % of line length.

In spite of estimation fault points in variable ranges, the estimation process (in contrast with traditional methods) is desirable. The main advantage of the method is no need to system parameters and system fault current measurement.

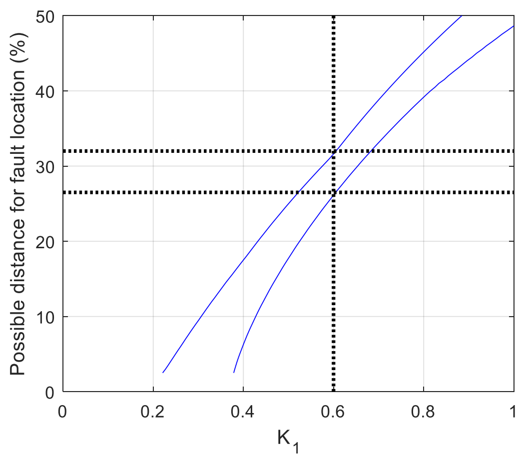

Figure 9. Possible distance for fault location versus K_1.

Conclusion

In this paper, a new method based on voltage measurement is performed to estimate accurate fault point distance in two-terminal transmission lines. The method is accompanied by morphology as proposed modern signal processor used in protection. The technique used the stationary reference frame theory to extract the fault locator criterion. One of the advantages of proposed technique is that the presented fault locator is independent of current measurements. Therefore, removing the current transformer makes this technique effective and simple with reasonable accuracy in fault location. Due to CT elimination, this method leads to a low-cost fault location. The morphology technique makes the method independent of system parameters. Hence, this consequence is the important priority of method in contrast with traditional cases. Simulation results confirm the capabilities of the presented technique in accurate fault location.

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